

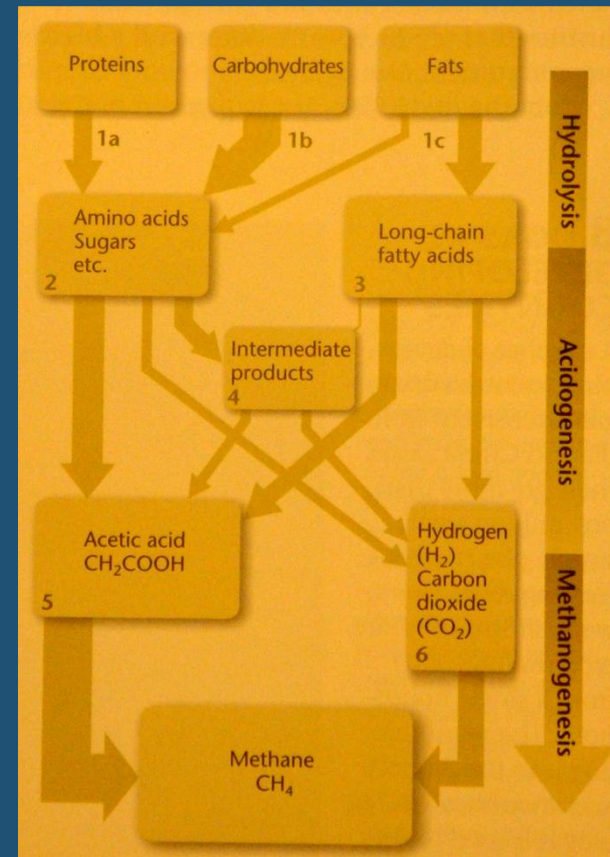
Anaerobic Digestion of Biomass

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What is Anaerobic Digestion

- A microbiological process that anaerobically (in the absence of oxygen) decomposes biodegradable materials.
- Consisting three main phases (hydrolysis, acidogenesis, and methanogenesis).



Source: Aarhus Uni. Denmark



What is Biogas

- A combustible mixture of gases
- Other names: manure gas, methane gas, marsh gas, etc.

Compound	%
Methane (CH ₄)	50–75
Carbon dioxide (CO ₂)	25–50
Hydrogen sulfide (H ₂ S)	0–3
Hydrogen (H ₂)	0–1
Nitrogen (N ₂)	Trace
Ammonia (NH ₃)	Trace
Oxygen (O ₂)	Trace



Source: Aarhus Uni. Denmark



A Brief History

- 1859: the first sewage plant in Bombay, Indian;
- 1895: a digester in U.K. lighted street lamps;
- 1970s-1980s: wide application in the world
- 2000s - : application steadily increasing

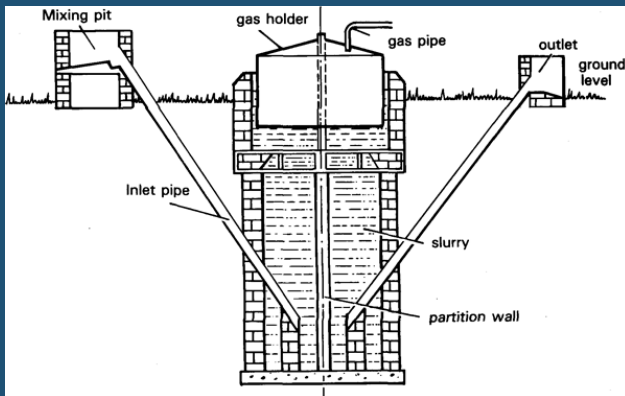


Photo: HEEE, China

Biomass for Anaerobic Digestion

➤ Animal Wastes



➤ Agro-industrial (food processing) wastes



➤ Municipal wastes



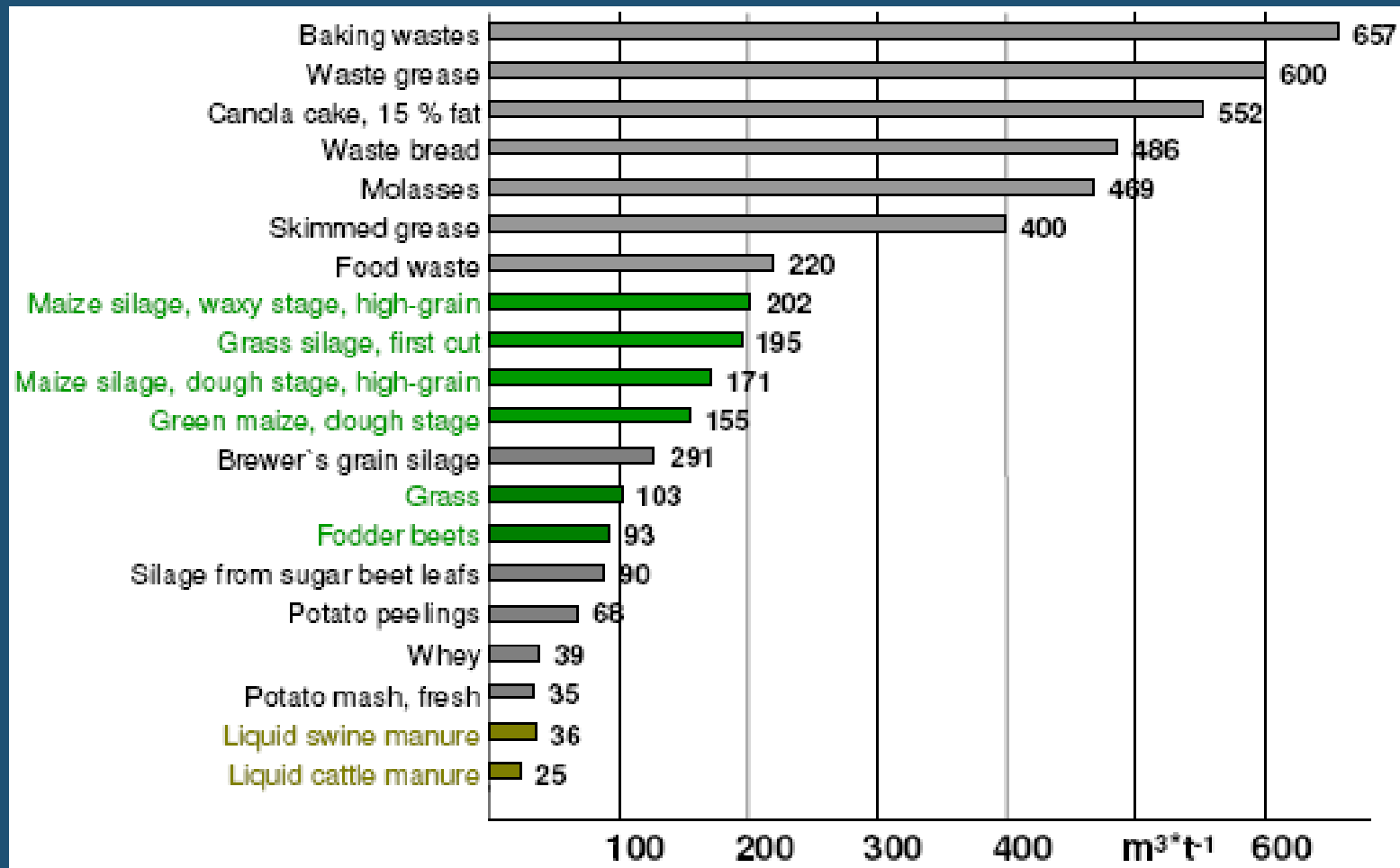
Estimation of Biogas Production

- Based on COD
1 kg COD = ~ 0.35 m³ methane
- Based on total solid (TS)

Manure	TS, %	Biogas production		CH ₄ , %
		m ³ /t manure	m ³ /t TS	
Cow	18~20	40~50	210~300	60
Hog	20~25	55~65	270~450	60
Poultry	30~32	70~90	250~450	60



Potential Biogas Yields



Source: Mathias Effenberger, 2006; Curts, 2009

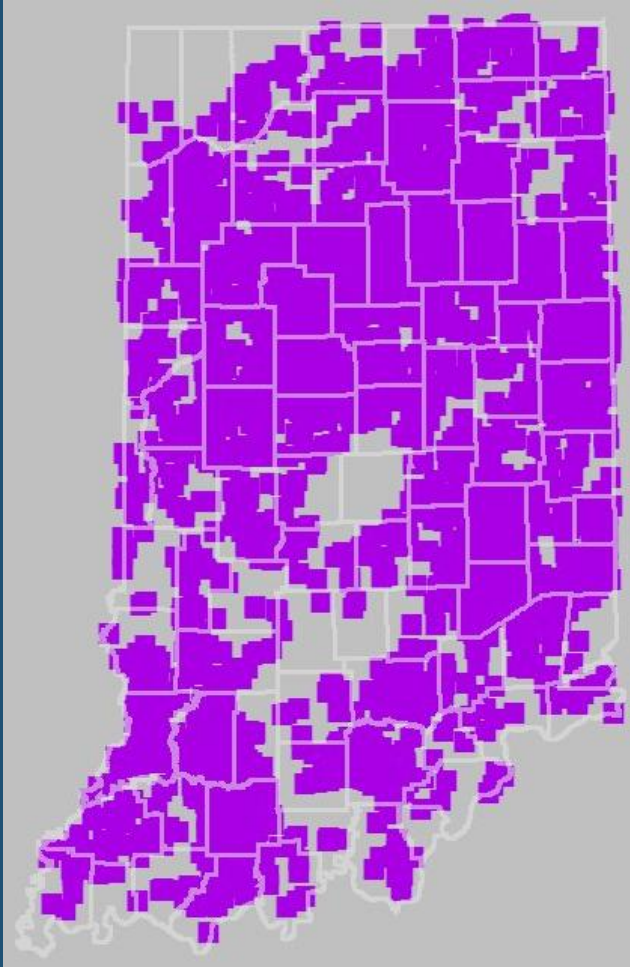


Biogas Resources

- Sufficient quantity
- Long term stability
- High concentration
- Animal wastes
- Agro-industrial wastes
- Municipal wastes
- Crop residues



Animal Wastes in Indiana



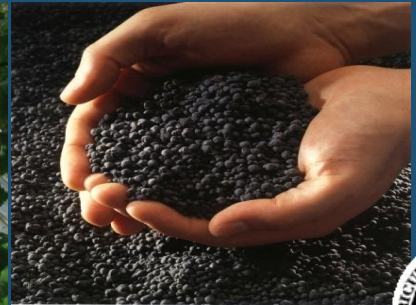
Source: www.Indianamap.org

- 2134 CFO and CAFO in 2010
- Manure production:
9.1 million tons/yr
- Potential biogas production:
455 M m³/yr (16.1 B ft³/yr)
Equivalent to 9.7 B ft³/yr natural gas,
about 2% of total Indiana natural
gas consumption



Environmental Benefits

- Reduce greenhouse gas effects
- Reduce odor.
- Reduce BOD and TSS by 80-90%.
- Reduce pathogen.
- Effective in killing weed seeds.
- Retain most of the nutrient content in digested manure.
- Mineralize organic nitrogen (Org-N) to ammonia ($\text{NH}_3\text{-N}$).



Fermentation Process

Temperature

- Thermophilic: 50-55 °C, up to 70 °C
- Mesophilic: optimally around 30-38 °C, or 20-45 °C
- Fermentation rate doubles at T increase of 10 °C

Solid content

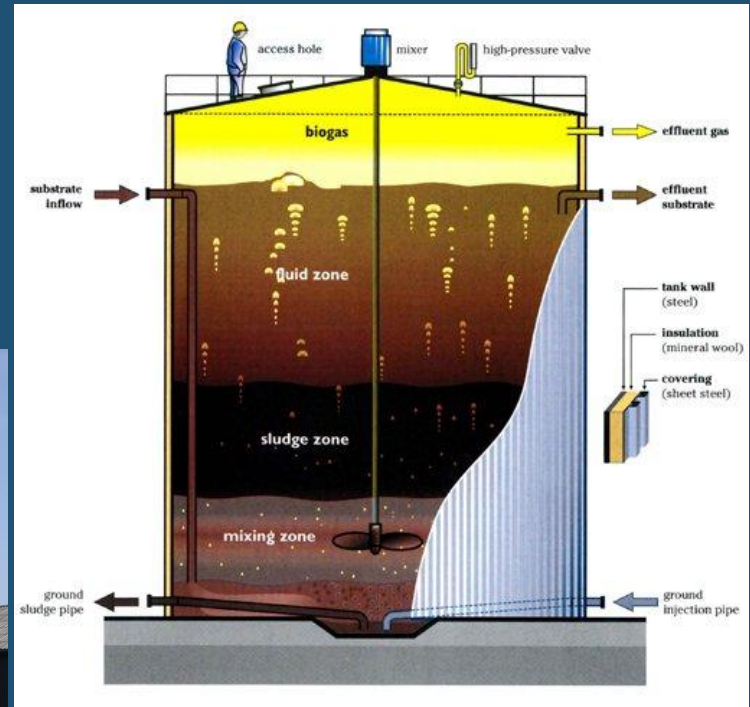
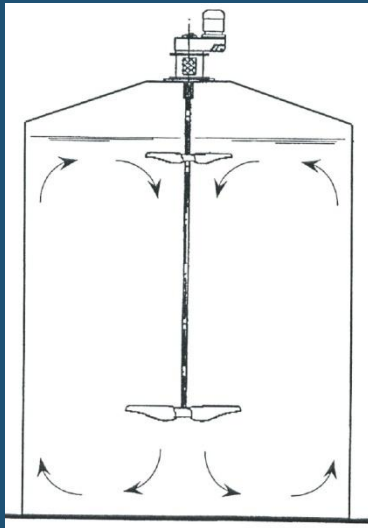
- Normally 5-12% total solid (TS)

Hydraulic retention time (HRT) for animal wastes

- Thermophilic: 10-15 days
- Mesophilic: 20-25 days

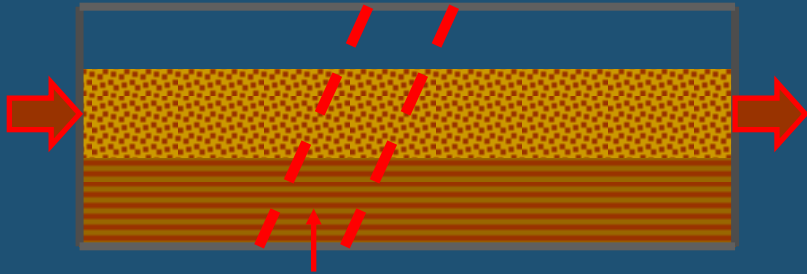


Digester Design: Complete mixing



A complete-mixing digester in Denmark

Digester Design: Plug flow



Source: Ben Teague *Plug Transport*

PROS

- Low maintenance
- Batch or semi-batch operation
- Rapid recovery/low retention time
- Can be used in different climates

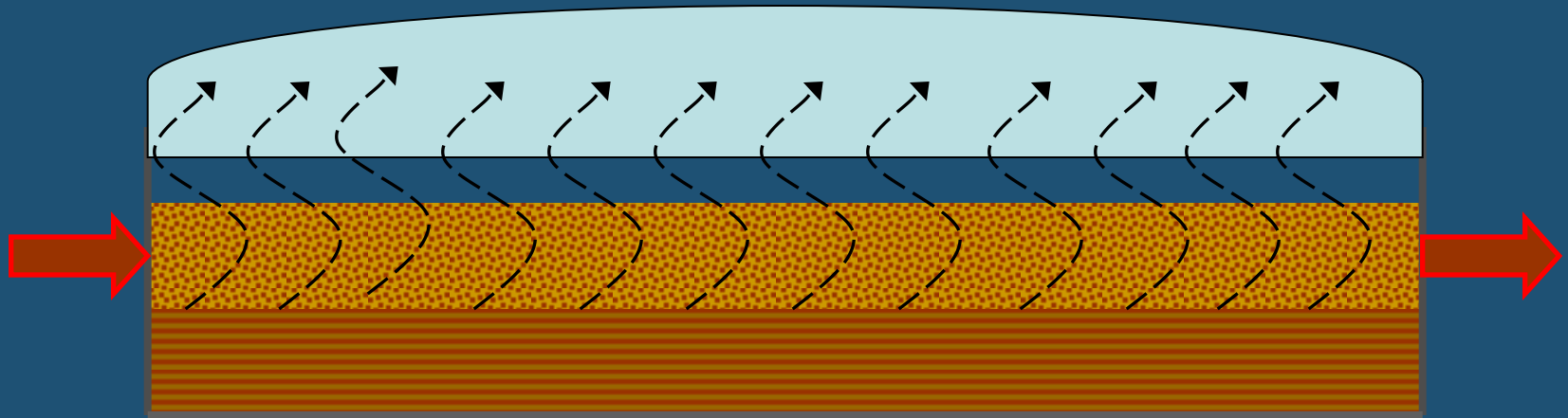
CONS

- Comparatively expensive
- Smaller reactor volume
- Labor intensive



A plug-flow digester in Germany
(Photo: Dr. K. Sheng)

Digester Design: Covered Lagoon



PROS

- Least expensive
- Low maintenance
- Low solids manure

CONS

- Land availability
- Efficient only in high temp climates
- High retention time

Source: Ben Teague, Mississippi Technology Alliance, Mississippi Alternative Energy Enterprise

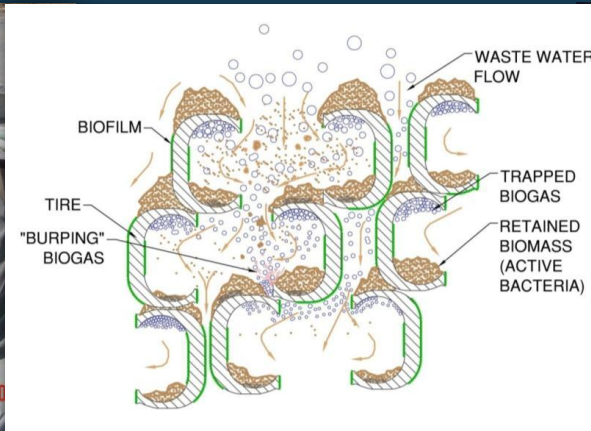


Other Digester Types

1. Batch- fed reactor
2. Suspended particle
3. Anaerobic filter
4. Up-flow solids reactor
5. Up-flow sludge blanket reactor
6. Anaerobic pump digester
7. Fluidized - and expanded - bed
8. Fixed film



TIREPower Anaerobic Digester



1/20th Scale 2005/2006

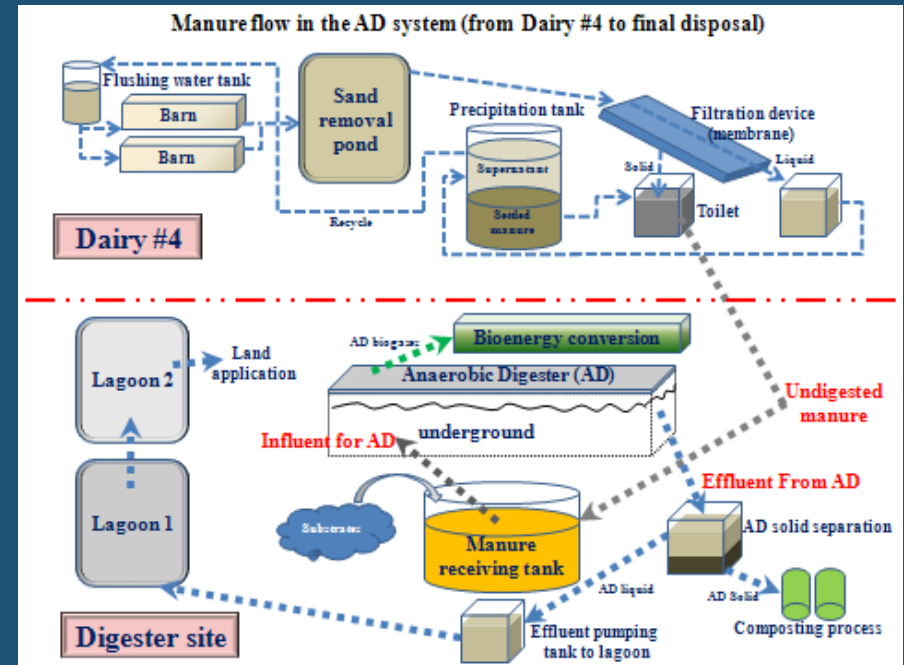


Basic module 800,000 gallons

Source: TIREPower LLC

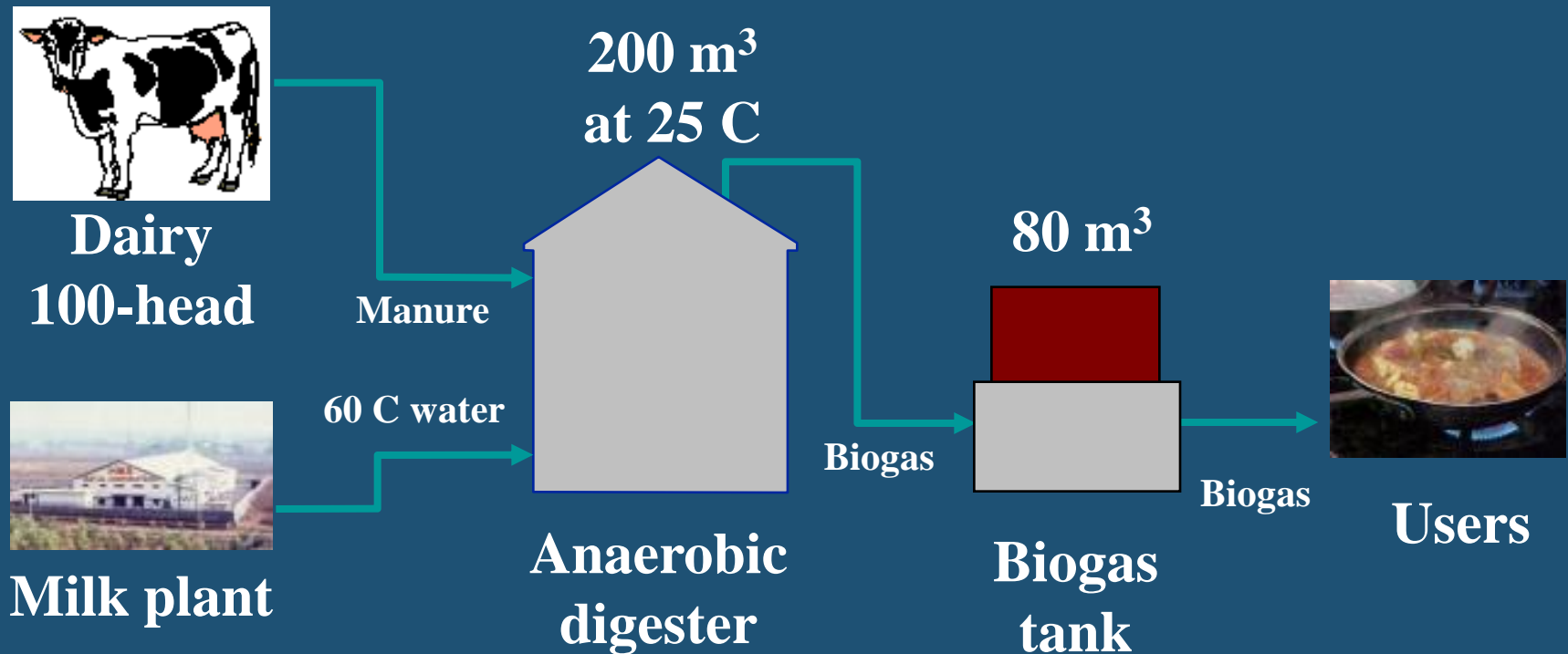


Community Digestion System, WA



Source: Washington State Uni.

Biogas for Cooking, Heating, & Lighting

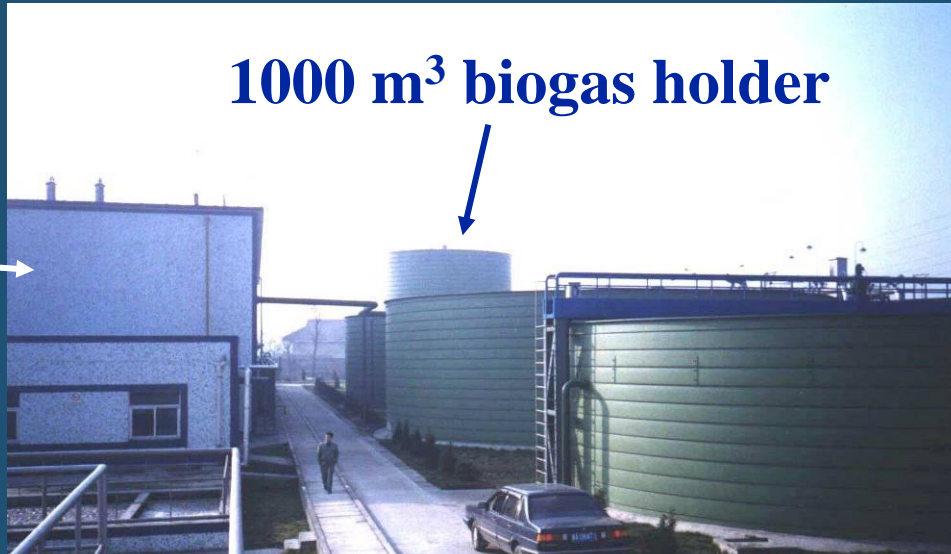


Layer Farm Digester System in China

8000 m³
UASB
digester

1000 m³ biogas holder

1500 m³ x 4
SBR



Boiler



Generator



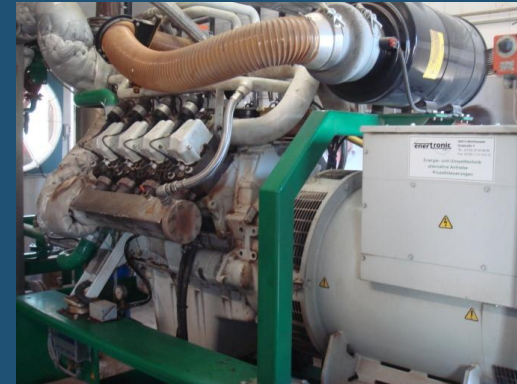
Restaurant

Photos: Hangzhou Energy & Environmental Engineering Co. Ltd.



Biogas for Electricity Generation

Animal	Biogas production, ft ³ /d	kWh/hd/day
Cow	65-80	2.5-3.7
Beef feeder	45-55	1.8-2.2
Sow	5.0-7.5	0.2-0.3
Finisher	3.5-5.5	0.15-0.22
Nursery	1.4-2.1	0.06-0.09
Laying hen	0.25	0.01



Biogas generators in Germany
(Photos: Dr. K. Sheng)

Biogas Use in Vehicles

Biogas station and
biogas car in Germany
(Photos: Dr. K. Sheng)



A biogas bus in Linköping, Sweden
(www.Wikipedia.com)

Biogas Processing for Vehicles



Purification

CH₄: from 60% to 95%

CO₂: from 35% to 3%

H₂S: < 10 ppm

O₂: < 0.5%



Compression

Into cylinder: 250 atm



Storage/transportation

1 m³ (35 ft³) bio-fuel = 1.2 L (0.3 gal) gasoline

Source: HEEE, China



A Future Trend of Biogas Use

A 20,000m³/d vehicle bio-fuel
biogas system under
construction in China



Source: HEEE, China

Indiana's Fair Oaks Farms later this year: 42 new trucks - powered by
biogas from 6 digesters -- to deliver milk in Indiana, Kentucky and
Tennessee.



Agricultural Biogas Production in USA

Table 2. Number of Operating Anaerobic Digester Projects by Animal Type

Farm Type	Total Digester Projects	Plug Flow Projects	Complete Mix Projects	Covered Lagoon Projects	Other Projects
Dairy	126	74	27	16	9
Swine	24	2	5	15	2
Poultry	5	1	4	0	0
Beef	2	2	0	0	0

Figure 4. Energy Production by Anaerobic Digester Systems: 2000 through 2009

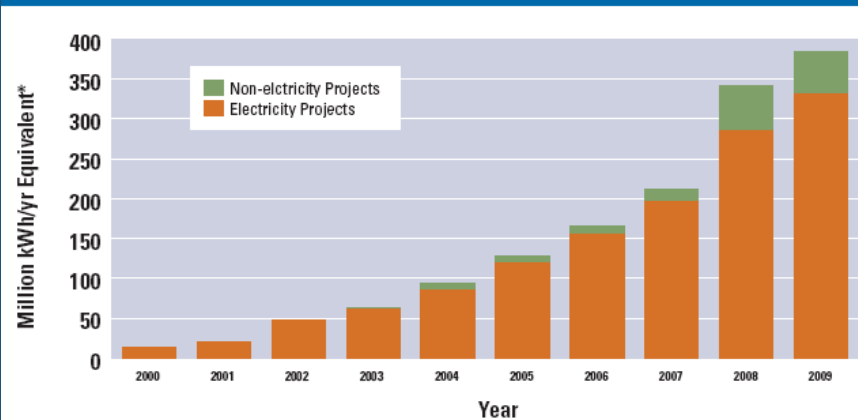
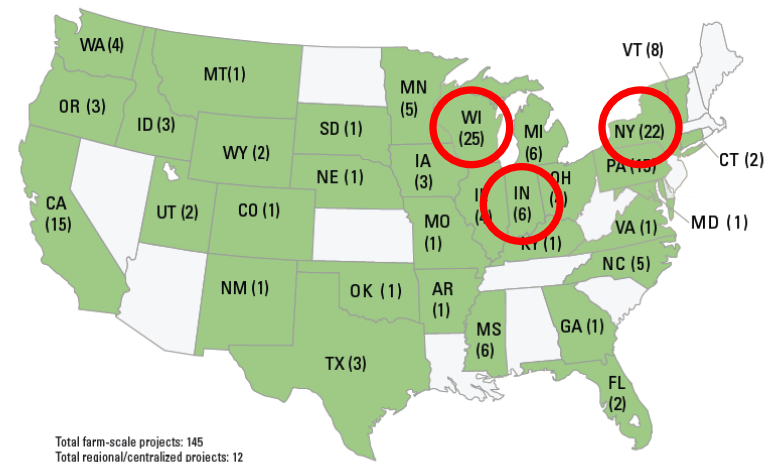


Figure 2. Operating Manure Digester Systems by State (July 2010)



Source: U.S. EPA AgSTAR



Biogas in Germany

- Biogas electricity generation system: from 450 in 1997 to 4,500 in 2007
- Capacity: from 100 MW in 2000 to 1,700 MW in 2007
- Increased bio-fuel for vehicles and natural gas grid
- World's largest biogas system using corn stalks (250,000 m³/d) built in 2009



Source: HEEE, China



Biogas in Switzerland

- The first country using biogas in vehicles
- 15,000 buses and taxis in Bern using bio-fuel.
- Biogas resources: municipal wastewater sludge and biological wastes



Biogas in China

- Large and medium size digester systems: 2,761 in 2008
- Millions of small family-size digesters
- Biogas production: equivalent of 0.34% of national natural gas consumption
- Biogas use: heat and electricity generation, started vehicle fuel use



Photos: HEEE, China



**THANK
YOU!**



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